Human Health Impact of E-Waste in Mexico

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Abstract. Mexico is the third electronic waste generator in America, only under the U.S. and Brazil. The main contribution of this study is a proposal of a sustainability model based on the generic cycle (Reduce, Recycle, Reuse) that allows extending the useful life of electronic waste through the reuse of components. It is known that the elements that contribute to this are: 1) the excessive technological consumerism, 2) the average short life cycle use of computers, and 3) the huge amount of mobile devices, batteries, and other gadgets left away due to obsolescence. These phenomena bring every day to increase the generation of electronic garbage, contributing environmental pollution and the poisoning of soil, water, and air. This work shows a methodology with the following elements; i) interviews, ii) survey, iii) data analysis, iv) correlations, and v) results over the impact of human health. In addition, the role they play in the context of problematic cities is discussed, with the companies that develop software that require greater hardware re-sources so that their applications work in the best way, which generates a limited lifetime in the devices and that the software that is built requires more resources for its optimal operation; thus, advancing the useful life and becoming technological waste. The new proposed model is based on; 1) awareness (reduce and reuse), 2) recycling (techniques and ways to reuse components so that it does not become garbage) and 3) the solution-prevention that helps minimize the impact on human health (reuse).

Keywords: E-Waste · Survey · Sustainability model · Health impact

1   Introduction

In recent years, the human being has been the cause of the deterioration of the environment, it is a topic of interest for nations, governments, and organizations; this is because there has been no culture of caring for the planet. Many are the factors can be mentioned as the cause, but among the most important are: 1) the generation of pesticides and chemical products, 2) deforestation, 3) industrial and domestic waste, 4) fossil fuels and 5) high rates of garbage production, among many others.

Technological development has been very useful for humanity; it has allowed many human activities to be carried out in an easier, faster, and higher quality manner. However, in the last two decades, it has caused great problems with the generation of electronic waste (E-waste). It is currently a serious problem, due to its increase and its inadequate treatment and disposal in many countries. E-waste is burned in open spaces and is disposed of in spaces that pose risks to the environment and human health. This represents a challenge for sustainable development that is one of the goals of the global agenda for the year 2030 towards a sustainable world [1].

E-waste is the result of several trends, such as the global information society that is growing at high speed, a growing number of users of new technologies and the Internet of Things (IoT), rapid technological advances that are driving innovation, efficiency and social and economic development.

In 2017, half of the world's population was already using the internet, networks, and mobile services, which resulted in many people using more than one electronic device, thereby promoting shorter replacement cycles, that's because people are attracted to the newest technology. Specifically, middle-class society worldwide that is able to spend more on electronic devices and consequently generate more garbage.

Although there are several proposals to develop a sustainable model for the management of E-Waste in large cities, many of these have put aside the issue of the impact on human health, in addition to evaluating the population's perception of the problem. In this work, a methodology was used to define a model that allows us to understand the sustainable management of WEEE. The investigation includes the following steps; 1) stakeholder survey, 2) interview with experts, 3) analysis of the perception of the problem among the respondents, 4) proposal of a model that includes the results of the survey.

2   Literature Review

2.1   E-Waste Context

According to [2], all the countries in the world generate a total of 44.7 million metric tonnes (Mt.) per year, which is equivalent to 6.1 kilograms per inhabitant year (kg/inh) on average worldwide. According to this trend, it is expected that by the year 2021 there will be an increase to 52.2 Mt., which is equivalent to 6.8 kg/inh. Of these 47.7 Mt. it is documented that only 20% is collected and properly recycled (this is equivalent to 8.9 Mt.), the most problematic aspect of this is that the remaining 80% is not

documented where it is taken, it is thought to be thrown in garbage dumps or in conditions impossible to recycle.

In this context, Asia produces 40.7% of electronic waste worldwide, followed by Europe with 27.5%, Americas with 25.3%, Africa with 5%, and Oceania with 1.6%, as shown in Fig. 1.
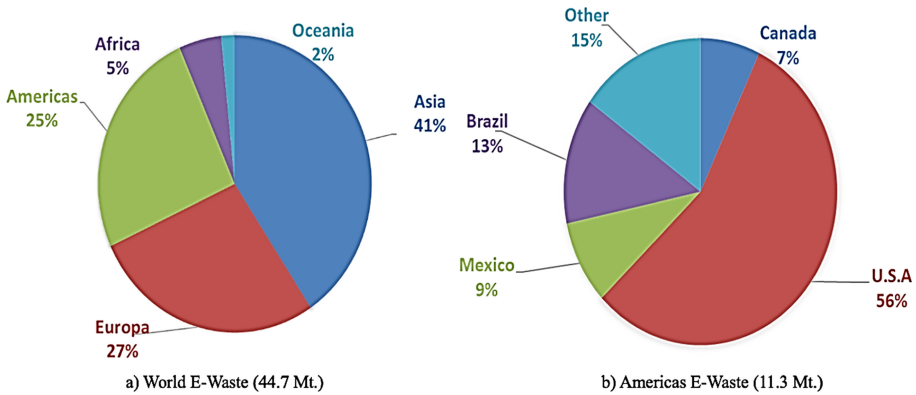
Fig. 1. Percentage of electronic waste generated in 2016 a) by continent and b) in America [2].

Of the 11.3 Mt that America generated, it is calculated on Latin America that Brazil contributed 1.5 Mt and Mexico 1 Mt, thus becoming the largest generators of electronic waste in America only below the U.S. who contributed 6.3 Mt, which is equivalent to the sum of all the countries in Latin America.

2.2 E-Waste in Cities of Mexico

It is recognized that in Mexico (with a population of 125 million inhabitants in 2019) there are 52 cities with a population ranging from 1 million inhabitants (Minh) to about 9 Minh on Mexico City. Many of these together with other cities conform to large urban areas [3]. In [4] describes that these agglomerations together with human activities generate a strong impact on the environment, increasing the ecological footprint per capita. The generation of garbage and its adequate disposal is a challenge for these large urban areas that bring together several cities. In Mexico, the largest areas per Km^2 are the metropolitan areas; from Mexico Valley (21 Minh), Guadalajara (5 Minh), Monterrey (4 Minh), Puebla-Tlaxcala (3 Minh) and Toluca Valley (2 Minh). The city of Morelia is considered one of the fastest-growing areas in the central-western part of the country with a population of 1 Minh.

On [5] describes the introduction of the new legal waste norm NADF-024-AMBT-2013 in Mexico City in July 2017; this mandates the new segregation of residual waste into five fractions: 1) organic, 2) recyclables, 3) non-recyclables, 4) hazardous and 5) bulky waste. Based on this standard there are three alternatives proposed: a baseline scenario with composting of organics, a scenario that involves anaerobic digestion of organics, and a mechanical–biological treatment scenario with no source separation.

Despite this norm in the cities of Mexico, there are still no clear policies for the separation, recycling and prevention of e-waste. It has also been observed that this norm is not used in the states' capital cities in the interior of the country with more than 1 million inhabitants, this leads to not having regulations that help to solve the problem of contamination by different types of garbage.

2.3   Human Health

In [6] describes that in Mexico City, garbage collection comprises a combination of formal and informal sectors. The study of the electronic waste recovery chain becomes a very important topic to avoid the impact on human health. Regulations and public policies should be part of a sustainable model for handling E-waste. The model proposed in Cruz-Sotelo comprises the phases: 1) source of the garbage, 2) collection and disposal, 3) sales of components that can be recycled, 4) recovery and 5) responsibility of actors.

To measure the impact on human health, the kilograms per ton recycled is used (1000 kg/tr), metals and plastics that can be recycled and are components of refrigerating equipment, large and small electronics, televisions (TVs), and monitors, for equipment of electrical and electronic lighting.

The plastics used are polystyrene (15.9 kg/tr), acrylonitrile butadiene styrene (9.8 kg/tr) and methyl polymethacrylate (3.29 kg/tr) that may contain polycyclic aromatic hydrocarbons (PAHs) [7], polychlorinated biphenyls (PCBs) [8], brominated flame retardants (BFRs) [9] and diphenyl ethers (PBDEs) [10] in concentrations less than 1 kg/tr.

The metals and rare-earth metals that have been detected are aluminum (16 kg/tr), cobalt (0.008 kg/tr), commercial refrigerant (with some metals), copper (10.8 kg/tr), and gold (0.045 kg/tr). Gravel with metals (9.6 kg/tr), lead (2.68 kg/tr), manganese dioxide (0.009 kg/tr), nickel (6.95 kg/tr), palladium (0.070 kg/tr), silver (1.37 kg/tr) and others (5.5 kg/tr) [6, 11].

These components in the open air and in garbage conditions can be harmful to human health when they are exposed to rain and sun, which in contact with humidity form leachates [12] can become toxic and contaminate aquifers, rivers, and lakes.

3   Methodology

Once the problem related to electronic waste in Mexico has been identified and the impact on human health is known, the scope of this work is described, this being a study that combines different types of investigation, such as: 1) exploratory, 2) transversal, 3) descriptive and 4) correlational. As indicated in [13], The steps to follow to achieve this research are shown in Fig. 2.

3.1   Survey

To establish the population to be surveyed, two metropolitan areas in the central-western region of Mexico were delimited. For the metropolitan area of Guadalajara, the
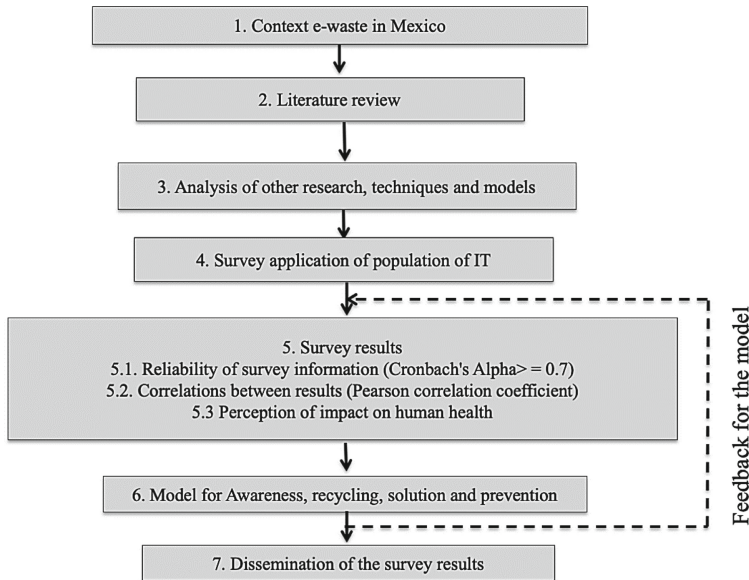
Fig. 2. Proposal methodology used for the construction of a model based on the results of the survey among university students about information and communications technology.

sample of the Universities of Guadalajara and ITESO was selected. For the Morelia metropolitan area, it was carried out at the universities of UNAM, TecNM, and UTM. The survey was carried out among the students, professors, and researchers of said institutions.

The survey was designed with 19 items of which 9 of these are based on the Likert scale, which allows obtaining the perception of the respondents about the most important variables described in the 3 axes as shown in Table 1.

The population was calculated at 1000 people, who are users of information technologies in different universities. With a 95% trust level and a standard error of 5%, the number of people to be surveyed was obtained, as shown in Table 2.

The reliability study was generated using Cronbach's Alpha, applying it to the information of the 285 people surveyed, resulting in .676; demonstrating the reliability of the information obtained. Next, the study of correlations was generated using the Pearson bivariate, considering only the medium-high correlations, the result is shown in Table 3.

3.2   Survey Results

The results of the items selected from the survey are shown below, as shown in Fig. 3.

Respondents were questioned about the impact of WEEE on human health and their knowledge about the diseases that these generate when they become electronic waste. As shown in Table 4.

Table 1. Thematic axes of the questions, survey on WEEE.

Thematic axes	Item	Type
General Information	e-mail	Open
	I. Occupancy	Option
1. Awareness of WEEE	II. Tell us about the perception you have about electrical and electronic equipment waste (WEEE) which becomes "poison" for human health	Likert
	III. You consider the risk of contracting diseases such as anxiety, hypersensitivity, neurosis, depression, stress, among others. It is through contact with waste electrical and electronic equipment (WEEE):	Likert
	IV. Are you aware of the components of electrical and electronic waste (WEEE) such as; batteries, electronic circuits, monitors and bulbs, solar cells and cables, and semiconductors?	Options: yes, no
2. Recycle of WEEE	V. Describe the handling you give to the electronic waste you dispose of:	Options
	VI. Tell us about ways of recycling electronic waste that exist in your region, community or population	Options
	VII. From the following elements, indicate the level of responsibility (0 to 100%) for each element, about the solution and prevention of electronic waste; a) government b) technology providers, c) consumers (garbage generators), d) scheduled obsolescence, e) software that is not updated, f) fashion (influence of the media)	Level 0 to 100%
3. Solution and prevention on human health	VIII. To prevent health problems due to contamination by electronic waste, indicate the level of importance in percentage (0 to 100%) for each subsection independently	Options
	IX. Teaching your family about the risks of contracting diseases because there are no adequate places to recycle electronic waste generated in the cities of Mexico	Likert

In item V, people were questioned about the habits they have when disposing of WEEE, they were questioned about the management they give to the electronic waste when disposing of it. Giving, as a result, 45% say they keep it in a box or place of confinement, 25% throw it away, 20% give it away, 12% sell it, 27% take it to recycle and 4% do something else with WEEE.

Similarly, in item VI it was observed about ways of recycling that exist in their urban area, 37% say they use recycling events, 20% government programs, 13% through recycling plants, 13% with companies of technology, 12% make use of Non-Governmental Organizations (NGOs) and 5% other forms.

Table 2. Data to determine the sample

| Reference values	Results
n (sample) =	278
Trust level	95.00%
Z value	1.96
p =	50.00%
q =	50.00%
e =	5.00%
N (population) =	1,000.00

Table 3. Correlation for nine items

| Pearson correlation >= 0.4	V. where WEE end	VII. Responsibility				VIII. Prevention of health risks
		VII b) Business	VII c) Users	VII e) Software	VII f) Trend	
II. Poisonous components	0.42					
VII. a) Government		0.51	0.49			
VII. b) Supplier companies			0.66	0.46		
VII. c) Generating users				0.49	0.43	
VII. d) Scheduled obsolescence				0.44	0.55	
VII. e) Non updating software						0.42

In Fig. 4 shows the importance of the actors involved in the generation, recycling, and reuse of WEEE components in urban areas, item VII.

For item VIII regarding human health, questions were raised about the importance of preventing family members from the risks of contracting diseases, since there are no adequate places to deposit electronic waste. 74% of respondents considered it very important, 23% important and 3% indifferent. Finally, for item IX it was observed that of the total of respondents:
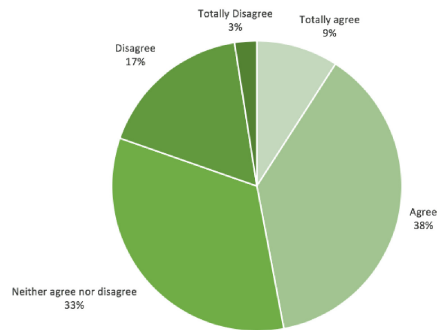
- 68% of them consider the implementation of public health programs very important
- 58% think that the solution should be emphasized among the population
- 41% advocate including the topic in educational programs
- 46% agree about promoting certifications for public and private companies
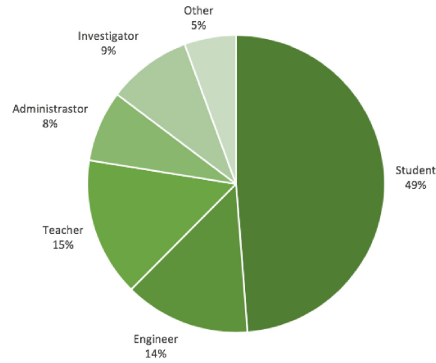
a)   Types of occupation of the respondents
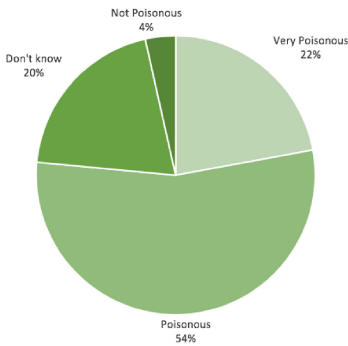

b)   WEEE as poison   c) Human health risks

Fig. 3. For Items I, II and III, a) Occupation and perception of WEEE, b) as poison and c) as a health risk 285 people surveyed.

Table 4. Item IV, perception of WEEE components that affect human health.

| Components	Yes	No
a) Batteries and/or accumulators contain elements such as lead and lithium that affect the kidneys, the brain, and the nervous system	89%	11%
b) Electronic circuits contain elements such as silicon that affect the bones, liver and cause psychological disorders	55%	45%
c) Monitors and fluorescent tubes (bulbs) contain elements such as mercury and toxic gases that affect the nervous system, eyes, and skin	76%	24%
d) Solar cells and semiconductors contain toxic plastics such as silicone that cause lung cancer	37%	63%
e) Cables and semiconductors contain arsenic that causes cancer in the respiratory tract	43%	57%
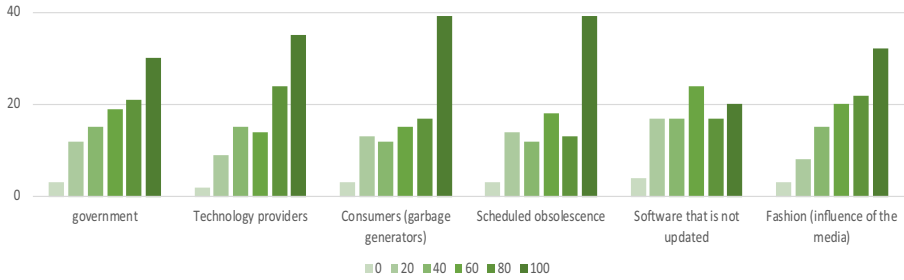
Fig. 4. Item VII, importance of the participation of the different actors in the recycling and disposal of WEEE.

- 51% agree in promoting the adequate disposal of WEEE
- 56% agree with having a greater number of recycling companies in urban cities

4   Discussion

According to the results of the survey, there is a need to generate activities that cover the three main axes: 1) awareness of WEEE in the population of urban cities and their adequate disposal; 2) recycling of WEEE where the responsibility is shared between the user generators and technology providers and 3) solution and prevention, to prevent WEEE from becoming electronic waste and causing harm to human health.

Therefore, a model is proposed that allows addressing the problem that meets the needs of each of the proposed axes. As shown in Fig. 5.
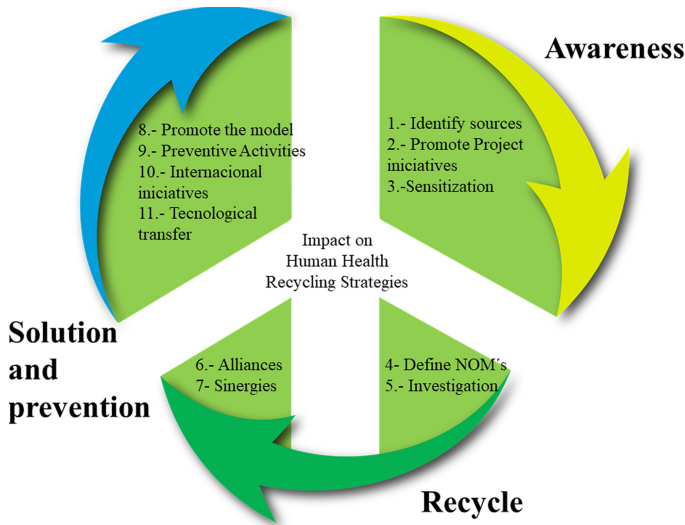
Fig. 5. Proposed circular sustainability model.

The strategies described in the model presented in Fig. 5 are based on the circular model proposed in [14], which are described in eleven items to solve the problem of electronic waste. The proposed model contemplates the same strategies classified in consciousness, recycling, and prevention/solution. Emphasis is placed on the impact on human health, which is described below.

Awareness:

1) Permanently identify the sources of WEEE generation and account for the volumes generated, trying to recycle the kg/t for plastics, metals, and other elements.
2) Promote investment initiatives and projects to develop the necessary infrastructure for the management of WEEE, using information technologies.
3) Develop greater efforts to raise consumer awareness of WEEE with the support of companies and decision-makers.

Recycle:

1) Define more precise NOMs that promote recycling, repairing, and reuse of WEEE. In addition, promote their eco-design to extend their useful life.
2) Promote research in Mexico through projects that consider aspects such as key actors, social framework, urban areas, and regulations.
3) Develop initiatives to strengthen academic, business, government, and society alliances for sustainable WEEE management.
4) Develop synergies between existing initiatives to avoid duplication of efforts and maximize existing resources for managing WEEE.

Solution y Prevention:

1) Publicize the impact of e-waste considering the three axes of the model for human health care.
2) Work on preventive activities such as certifications, dissemination, among the actors and thus avoid contamination by WEEE.
3) Respect international initiatives (ITU-T Study Group 5, PACE [14], and Step [15]).
4) Promote innovation and technology transfer for the sustainable management of WEEE.

The application of the model requires outreach and dissemination activities in urban cities that help raise awareness among citizens and e-waste recyclers about the impact this has on human health. It is observed that the surveyed population is aware of the problem caused by WEEE when it becomes electronic waste, but there are no clear ways to properly dispose of it and there are no known places to take it to recycle.

5   Conclusion

Based on the correlation study, respondents think that the highest correlations demonstrate the level of responsibility they have: 1) users and technology providers, 2) continuing with users and the government, 3) responsibility of users who generate

garbage due to the obsolescence of the software, 4) the obsolescence of the electronic equipment because it is not fashionable anymore. However, respondents also think that technology companies would not be responsible of management of WEEE without government regulations.

The survey revealed the response of students, teachers and engineers who are related to information technology, 54% consider e-waste to be a poison for human health and 38% consider it a risk to human health.

It was observed that the perception about the elements that most affect human health in order of importance are: 1) batteries, 2) electronic circuits 3) monitors and fluorescent lights. It was also observed that there is heavy impact related of solar cells and cables; when these elements are disposed cause cancer and damage to the respiratory system.

It was also found that 37% of respondents are aware of recycling events, 20% of government programs and initiatives, and 13% knew about events made by recycling plants and technology companies. However, they think that programs and initiatives will help the government, recycling plants and technology companies to improve the process of handling electronic waste.

It is necessary to take advantage of technology to generate a strategy that enables electronic waste generators to be closer to recycling companies.

Education is an important issue in the solution because there is a need to be included in the study plans and programs, from basic education to higher education; through mandatory workshops, school subjects, and/or courses in the areas related to IT and sustainability. This way the model can be a framework for reducing the ecological footprint in technological areas.

This new model considers the impact on human health, through strategies defined are aimed at reducing the E-waste. Building methodologies attached to the model would help implement public initiatives in cities that do not have regulatory frameworks. Therefore, it is necessary for the government to participate in promoting new norms that regulate the disposal of WEEE in Mexican cities.

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